Introduction

Sarawak exploration is dominated by the Late Miocene platform carbonates and pinnacle reefs discovery of Central Luconia sub-basin, Sarawak Basin, offshore northwest Borneo. The basin formed in Late Eocene to Oligocene extends over 40,000 sq.km and developed more than 200 carbonate build-ups (Longman, 1993). Since 1950s, all large structure of carbonate pinacles has been explored and left with uneconomical prospects and high geological risk (Wan Mohd, 2008). In 2019, PTTEP together with KUFPEC and PETRONAS Carigali has revived the Sarawak exploration activities and discovered a multi-TCF gas field of Lang Lebah Carbonate Pinnacle, which became a world top rank and the largest hydrocarbon resources of Malaysia in 2019. This paper will discuss on the journey of Lang Lebah discovery, guided by the novel multidisciplinary technical approaches and new exploration concepts.

The Lang Lebah field is located in the SK410B (Figure 1) Production Sharing Contract under PETRONAS’ Malaysia Petroleum Management unit. With the challenging operation of HPHT environment and limited reservoir characterization understanding, Lang Lebah field was partially tested by Lang Lebah-1/1RD in 1994 by JX Nippon with limited 2D seismic data and inconclusive exploration well result and the field has been abandoned for the past 25 years.

Figure 1: Location of Lang Lebah Field, SK410B PSC, Central Luconia Province, Offshore Sarawak (Janjuhah, 2017)

Method

In order to successfully explore remaining hydrocarbon potential in a mature basin, comprehensive exploration approach in carbonate reef was established. The approach requires integration of reservoir characterization (seismic inversion) and carbonate growth architecture identification. The multidisciplinary approach then alluded to the sweet-spot target for carbonate build-up appraisal program.

Reservoir characterization

The carbonate reservoir characterization achieves elastic rock property and facies classification using rock physics analysis, 3D seismic quantitative interpretation (simultaneous elastic inversion techniques) and probabilistically identified litho-facies focusing on Miocene-Pliocene carbonate build-up to propose sweet spot target.

Rock physics modelling: Rock physics modelling link between the petrophysical properties and the elastic properties of using nearby carbonate pinacles. The elastic properties of the rocks then determined through seismic inversion to be interpreted in terms of reservoir properties.

Inversion: simultaneous elastic inversion algorithm jointly inverts angle stacks to derive estimates of the elastic parameters including P-impedance, Vp/Vs Ratio, and density to determine carbonate reef facies. The generic workflow is to perform quantitative prediction of the lithology, porosity and fluid
distribution/content of the reservoirs by converting angle stack seismic reflection data to multiple calibrated elastic rock property data.

The result of reservoir characterization using simultaneous elastic inversion provide detailed information of carbonate facies and elastic property including Vp/Vs and computed porosity as shown in Figure 2.

![Figure 2: Reservoir Characterization result of Lang Lebah Field shows rock physics modelling, simultaneous deterministic seismic inversion of P impedance, and litho-facies classification of porosity distribution.](image)

**Carbonate Growth architecture modeling**

Lang Lebah Field is located in shelf margin of Central Luconia Platform (Figure 3). As the site is at the most windward position of the platform, Lang Lebah build-up carbonate comprised of healthy coral communities. Based on reefal facies in Lang Lebah discovery and analogue with modern carbonate ecosystem, the zonation of the carbonate build-up can be divided into six facies including Fore-reef/Inter island channel, Reef front, Reef crest, Back-reef/Reef flat, Lagoon and Islands, ordering from open sea to island respectively showed in Figure 3. The relative reservoir quality determines from the carbonate facies:

- **the reefal facies** or reef flat are composed of coral boundstone and mudstone fabrics.
- **lagoonal facies** is generally mud-prone facies with experienced low energy condition.
- **fore-reefal facies** or talus is considered a non-reservoir due to poor sorted debris resulting low porosity reservoir.

Apart from carbonate architecture, wind direction relative to carbonate location is one of the most important element to differentiate reservoir quality of carbonate build-up. High wave energy (windward direction) provides large flux of nutrients, comprise more diversity and healthy coral, and create proper condition to grow coral than the leeward direction. Thus, windward direction is generally better reservoir quality compared to leeward direction. According to well result of the Lang Lebah-1RDL, the well is positioned in the leeward direction and penetrate into fore-reef facies (talus), which is comprising of mudstone to wackestone resulting in tight reservoir interpretation in 1994.
To explore Lang Lebah potential and locate sweet spot target, the carbonate growth architecture modelling and reservoir characterization has been conducted for predicting the reservoir quality by matching the carbonate growth history with Stratigraphic Forward of Carbonate Modeling.

![Image](image1)

**Figure 3:** Cycle V Paleo-depositional environment map and Reefal facies zonation of Lang Lebah based on model analogy (modified from Epting, 1976)

According to the result of Lang Lebah field modeling, the reef has ability to grow faster vertically than the rise of sea level, thereby allowing for outward as well as upward growth. Each facies developed different communities and forms, and has signature sedimentological characteristic. The result also shows a good correlation from litho-facies classification from seismic inversion, reservoir facies, and rock typing of Lang Lebah field along with regional wind-direction and carbonate growth modeling.

**Integration and Sweet Spot well-targeting approach**

The multidisciplinary studies have been conducted including reservoir characterization using simultaneous seismic inversion and carbonate growth architecture modeling. The carbonate growth architecture, including of pre-growth setting, growth history according to sea-level changes, build-up architecture restoration, facies classification and reservoir quality prediction, are interpreted based on 3D seismic that corresponding to sequence stratigraphy; integrating well data and nearby well conventional core interpretation. Diagenesis features, such as tight layer, karst, and cavern, are identified and express in this study. By integrating surface seismic data and seismic inversion result, the difference of carbonate depositional facies corresponding to different rock properties and reflectivity in seismic reflection of Lang Lebah structure. Rock physics and Seismic Inversion achieve reliable seismic reservoir characterization result with deliverable of elastic properties, probabilistically identified litho-facies, and petrophysical properties that help to properly well targeting into the sweet spot of carbonate build-up. For Lang Lebah field target, the appraisal well Lang Lebah-1RDR2 was proposed at the reef crest of windward location, where relatively high inverted effective porosity (simultaneous seismic inversion result) and possible good reservoir quality of boundstone carbonate facies (carbonate growth architecture modeling result) located shown in **Figure 5**.

In June 2019, Lang Lebah-1RDR2 appraisal well successfully proves good reservoir quality facies as predicted as opposed to talus facies that entered in Lang Lebah-1RDR1 in 1994, which hindered the hydrocarbon potential of Lang Lebah field for the past 25 years. This successful results also altered the exploration perceptions and leads significant gas discovery in Sarawak.
Figure 5: The Sweet Spot targeting maps support the Lang Lebah-1RDR2 to position the well in the good facies distribution by overlaying the RMS-amplitude porosity of intra layers sum of litho-facies inversion porosity from simultaneous seismic inversion integrating with the carbonate growth architecture modelling of windward-direction.

Conclusions

In order to locate the sweet spot of appraisal well, we implemented multidisciplinary work of seismic inversion workflow to provide reservoir characterization of petrophysical property of Lang Lebah Field, and carbonate growth architecture modelling for predicting carbonate facies and rock-typing. The journey of Lang Lebah discovery can be summarized with this integrated and comprehensive geological and geophysical approach to successfully explore carbonate build-up of Lang Lebah field.

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